A NEW METHOD OF INTERPRETATION OF SELF-POTENTIAL FIELD DATA*

L. DE WITTE†

ABSTRACT

In this paper a new, efficient method is worked out for the interpretation of self-potential field data. Interpretation of location, depth and dip of the ore body is made, using a pattern of equipotential lines. The negative center and the positive maximum of the potential are found and also the so-called "mid-value" point. The dip α, can be determined accurately for values between 5° and 85°. The method cannot be used for vertical polarization. The depth and location can be found with relative accuracy for $\alpha > 10°$. The main advantage of this new method is the ease of interpretation and a greater accuracy for the high-dip angles.

It should be stressed that, for correct and accurate interpretation, the positive maximum is as important as the negative center. Therefore, it should be carefully sought during the field work, and mapped to its full extent.

INTRODUCTION

The existing methods of interpretation of self-potential data, obtained from prospecting for ore bodies, are cumbersome and commonly involve a large amount of guesswork.

An elaborate theory for the surface distribution of potentials was worked out by A. Petrovski.[1] The method of interpretation given by Petrovski uses the current densities, which are proportional to the derivatives of the potential curves for a fixed direction of traverse. This obviates taking into account a base-line potential.

A later method given by W. Stern[2] is based on formulas derived from assuming the ore body to be a polarized bar. The potentials measured in the field are used as such, which gives inaccuracies due to the absence of a fixed base line, relative to which the potentials are defined. In the theory the potential at a large distance is assumed to be zero. In the field, however, the zero-potential is difficult to obtain due to the presence of spurious potentials caused by vegetation and percolation. It is also difficult to predetermine how far one has to go to find the "infinity-potential" for practical purposes, as the positive maximum caused by the ore can be far from the center of the ore body for low-dip angles.

The interpretation here presented is based on Petrovski's theory, assuming the ore body to be a polarized sphere. A "mid-value" point is introduced which eliminates the zero-line difficulties and does not require the use of current densities, saving much work and minimizing errors in the interpretation.

* California Institute of Technology, Division of Geological Sciences, Contribution No. 469. Manuscript received by the Editor June 17, 1948.

† California Institute of Technology, Pasadena, California.

[1] A Petrovski, *Philosophical Magazine*, *5* (1928), 334, 914, 927.

[2] W. Stern, *Trans. A.I.M.E.* *164* (1945), 189.

The "mid-value" point is an improvement on the "half-value" point idea which was outlined by C. A. Heiland,[3] for a vertically polarized sphere.

As only three points are used for the interpretation, all of which are well defined by the equipotential pattern, inaccuracies due to distortion by topography are kept to a minimum.

THE THEORY OF INTERPRETATION

Figure 1 represents a hidden polarized sphere in a semi-infinite isotropic medium, and its image at equal distance above the flat boundary surface.

The vertical plane through the plus and minus pole is called the plane of

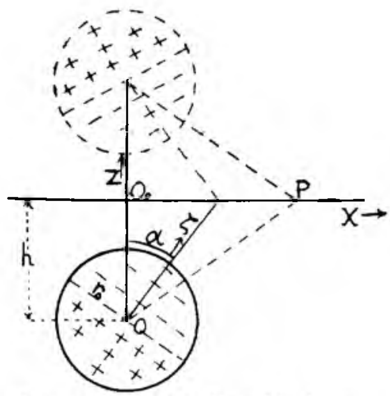

FIG. 1. Polarized body and its image.

polarization (here the plane of the paper). The x-axis is the intersection line between the plane of polarization and the horizontal boundary surface. The z-axis is vertically upward. The origin O_0 is vertically above the center of the hidden sphere. The polarization of the sphere is assumed to diminish by the cosine law with respect to the angle which is formed by the given direction and the axis of polarization (ζ).

$$e = E \cos \theta.$$

For any point p on the x-axis, Petrovski calculated the potential due to the field of the hidden sphere to be:

$$V = \frac{ER_0^2}{2} \frac{h \cos \alpha + x \sin \alpha}{(x^2 + h^2)^{3/2}}. \tag{1}$$

To find the abscissae of the maximum and minimum points, we take the derivative:

[3] C. A. Heiland, *Geophysical Exploration* (New York: Prentice-Hall, Inc., 1940), 673.

$$\frac{dV}{dx} = \frac{ER_0^2}{2}\left\{\frac{-3hx\cos\alpha + (h^2 - 2x^2)\sin\alpha}{(x^2 + h^2)^{5/2}}\right\},$$

$$3hx_m\cos\alpha = (h^2 - 2x_m^2)\sin\alpha,$$

$$x_m = -3/4h\cot\alpha \pm \sqrt{h^2/2 + 9/16\cot^2(\alpha)\cdot h^2},$$

$$a = 1/2(x_{m_1} - x_{m_2}) = h\sqrt{1/2 + 9/16\cot^2\alpha}. \tag{2}$$

The length $2a$ is the distance between the maximum and minimum point of the potential along the x-axis.

$$\frac{x_m}{h} = -3/4\cot\alpha \pm \sqrt{1/2 + 9/16\cot^2\alpha}. \tag{3}$$

Figure 2 gives the potential profile for $\alpha=45°$ and shows the relative position

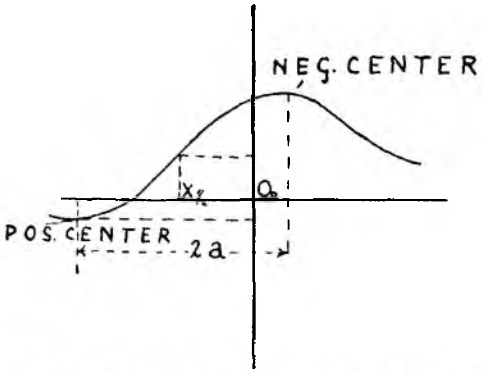

FIG. 2. Profile of the self-potential curve along the x-axis.

of the negative center and positive maximum. The potential is taken negative upward, while x is positive in the direction of the negative center.

We now define the "mid-value" point as the point where the potential $V_{1/2}$ has a value equal to $\frac{1}{2}(V_{\text{maximum}}+V_{\text{minimum}})$ and located between the negative and positive centers. We call its abscissa: $X_{1/2}$.

From equation (1) with $ER_0^2/2=A$, we have:

$$\frac{V_m h^2}{A} = \frac{\cos\alpha + x_m/h\sin\alpha}{[(x_m/h)^2 + 1]^{3/2}}; \tag{4}$$

$$V_{1/2} = 1/2(V_{\max} + V_{\min}) = F(\alpha)\frac{A}{h^2}\cdot \tag{5}$$

For any given value of α, we can calculate the above defined $(F\alpha)$ by first calculating $X_{\max}/h$ and $X_{\min}/h$ from equation (3). Substitution into equation (4) gives V_{maximum} and V_{minimum}.

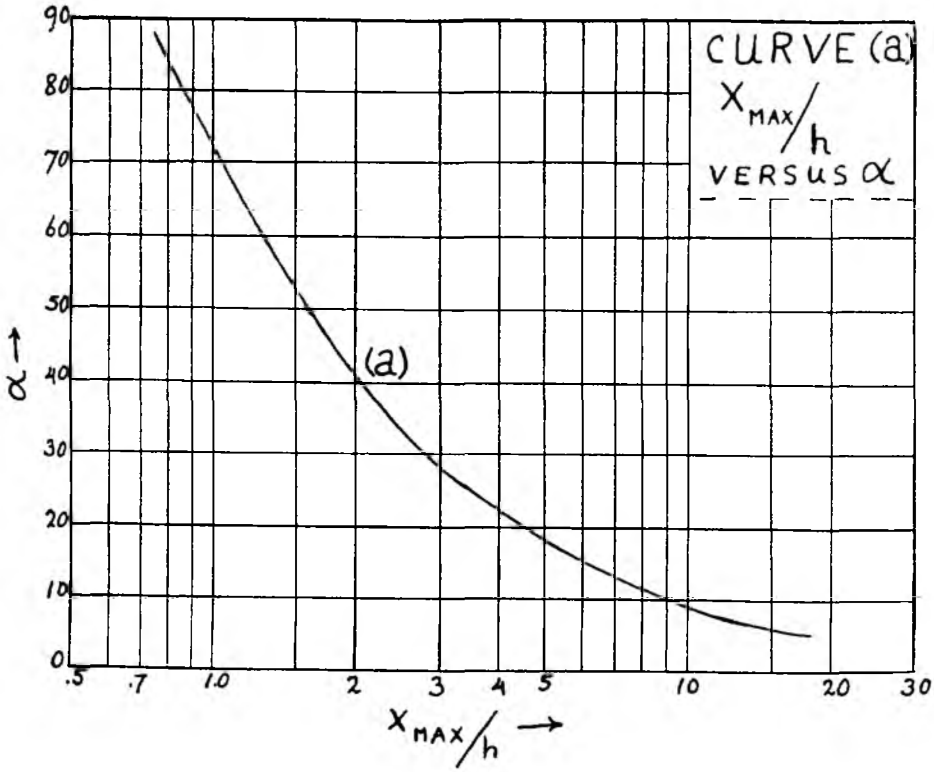

FIG. 3. The ratio of x_{max} divided by the depth as a function of the angle α.

Figure 3, curve (a) shows x_{max}/h as a function of α. Figure 4, curve (b) gives x_{min}/h and Figure 5 curve (c) gives a/h, obtained from equation (2).

For $X_{1/2}$ we obtain from equations (1) and (5) the identity

$$F(\alpha)\,\frac{A}{h^2} = \frac{A}{h^2}\;\frac{\cos\alpha + x_{1/2}/h\,\sin\alpha}{[(x_{1/2}/h)^2 + 1]^{3/2}}\,.$$

This gives $x_{1/2}/h$ as a function of α. See Table 1.

TABLE 1

α	a/h	$x_{1/2}/h$	$a/(x_{min}-x_{1/2})$	$a/(x_{max}-x_{1/2})$
5	8.60	−0.721	11.47	0.523
10	4.31	−0.573	5.90	0.546
20	2.18	−0.579	3.126	0.595
30	1.48	−0.493	2.20	0.647
40	1.14	−0.407	1.75	0.701
50	0.947	−0.323	1.48	0.755
60	0.829	−0.240	1.30	0.811
70	0.757	−0.160	1.19	0.870
80	0.719	−0.079	1.08	0.932

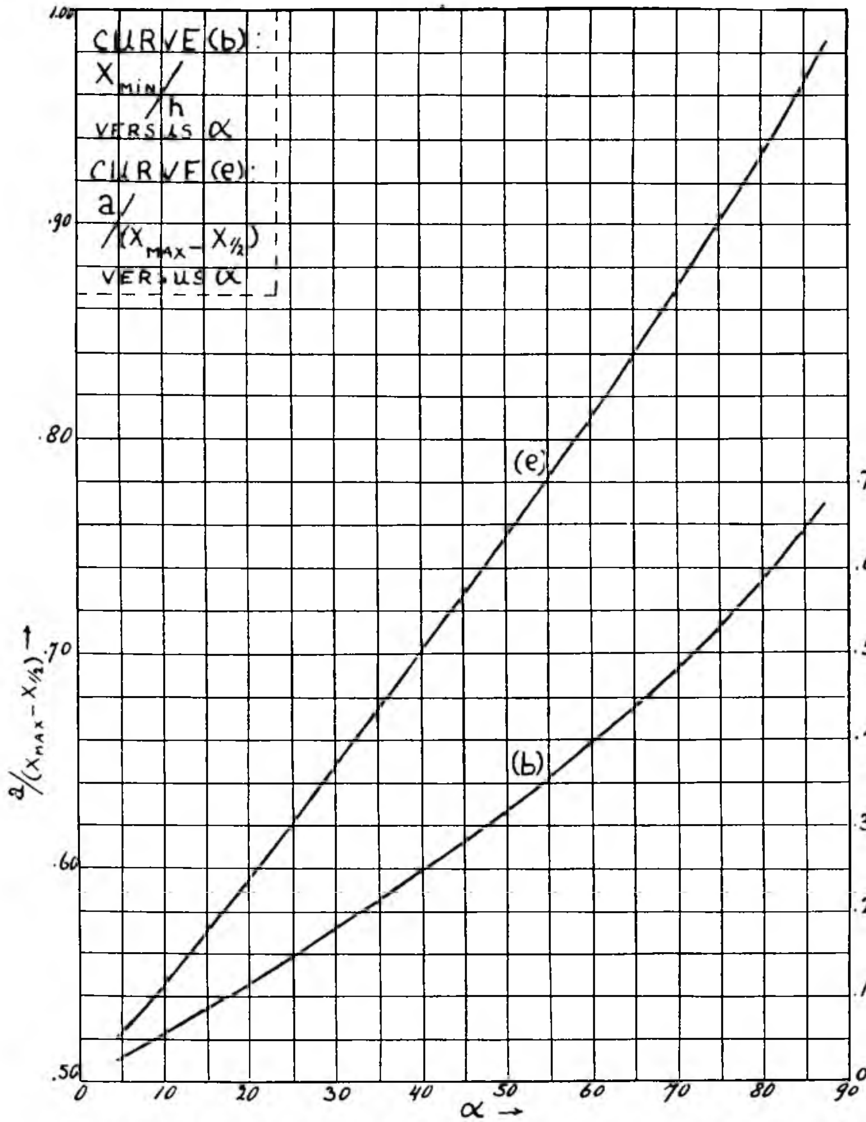

FIG. 4. Curve (b): x_{min}/h as a function of α. Curve (e): $a/(x_{max}-x_{1/2})$ as a function of α.

Table 1 also gives a/h for the entire range of α (from $a/(x_{min}-x_{1/2})$ and $a/(x_{max}-x_{1/2})$.

The latter values were obtained by first finding $(x_{min}-x_{1/2})/h$ and $(x_{max}-x_{1/2})/h$ and then dividing these quantities by a/h.

The length $(x_{min}-x_{1/2})$ and $(x_{max}-x_{1/2})$ can be measured along the x-axis. Curves (d) and (e) show them as functions of α.

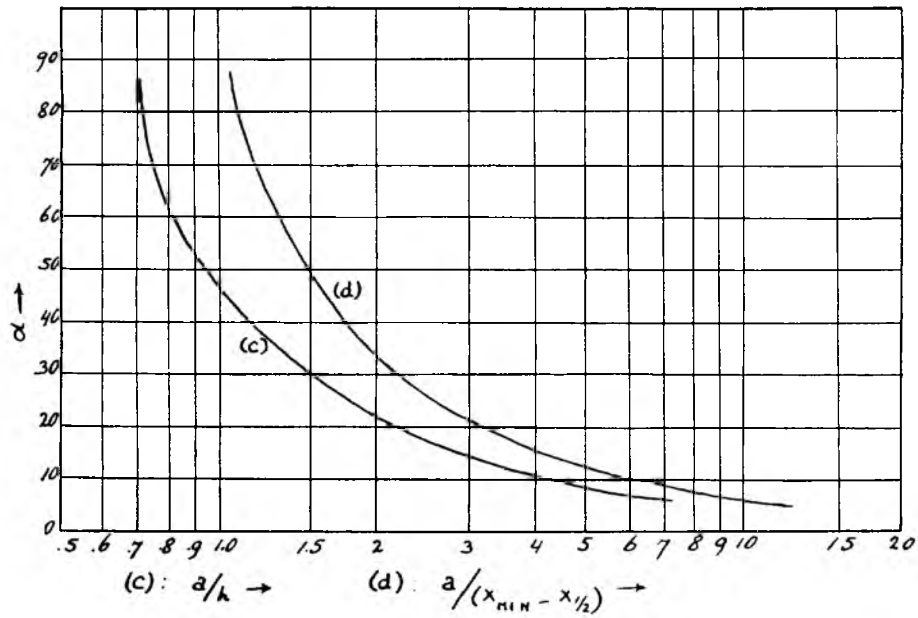

FIG. 5. Curve (c): a/h as a function of α. Curve (d): $a/x_{\text{min}} - x_{1/2})$ as a function of α.

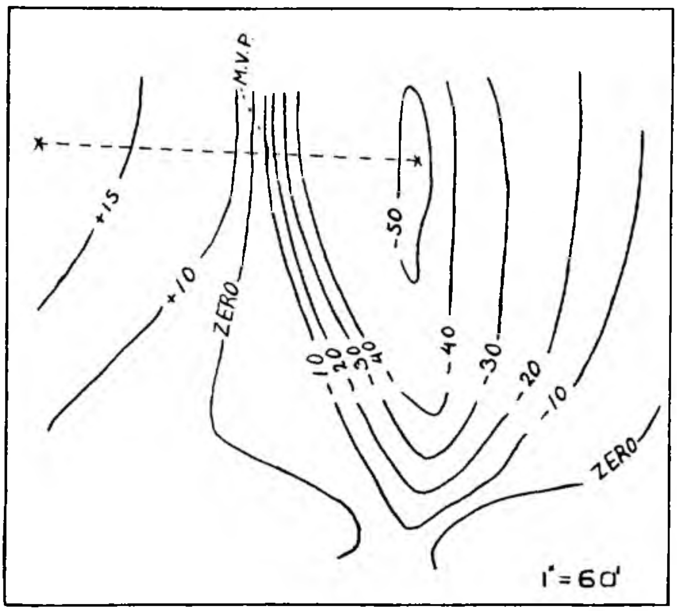

FIG. 6. Big Bend self-potential anomaly.

PROCEDURE OF INTERPRETATION

1. Measure a as half the distance between the negative and positive center.
2. Measure $x_{min}-x_{1/2}$ and (or) $x_{max}-x_{1/2}$ respectively as the distance between the negative and positive center and the mid-value point. Divide a by the latter.
3. From curve d or e find α.
4. For the value of α obtained find a/h from curve c. This gives us h.
5. From curve a or b find x_{max} or x_{min} which gives the distance of O_0 (the vertical projection of the center of the ore body on the surface) from the positive or negative center.

In practice h denotes the depth to the point where the water table intersects the ore body. The "center" is the midpoint of the section of the ore body made by the plane of the water-table.

NUMERICAL EXAMPLES

a) Big Bend anomaly (Surcease mine), see Figure 6.

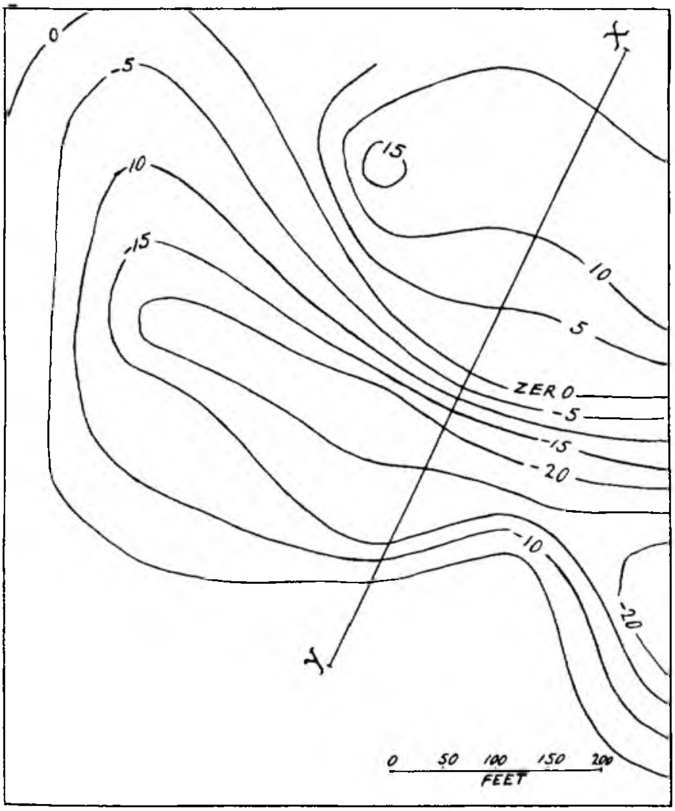

FIG. 7. Self-potential anomaly at Hope, British Columbia.

This example was taken from the professional thesis of S. Yüngül,[4] who interpreted the curves by Petrovski's current-density method.

The positive maximum value is approximately 18 mv. Midpoint value: $\frac{1}{2}(18-50)=-16$; $a/x_{\min}-x_{1/2}=1.3$.

Curve (*d*) gives $\alpha=60°$. For $\alpha=60°$, curve (*c*) gives $a/h=0.84$, $2a=180$ feet, so $h=90/0.84=107$ feet. From curve (*b*): $x_{\min}/h=0.395$, $x_{\min}=42.8$ feet, Yüngül found $\alpha=60°$ $h=106$ feet.

b) Hope mine (British Columbia), see Figures 7 and 8.

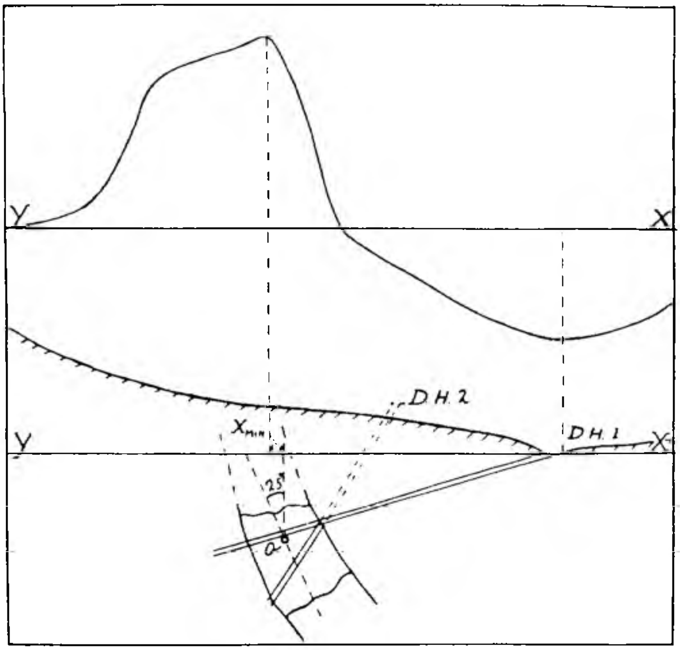

FIG. 8. Cross section and self-potential profile of the Hope anomaly along the line *XY* of Figure 7.

The equipotential pattern was constructed from a series of potential profiles given by J. J. Breusse.[5] The cross section (Fig. 8) was taken from an article by E. Poldini.[6] The potentials in Figures 7 and 8 are expressed in arbitrary units.

The anomaly is no type-example for representation by a polarized sphere. However, along the lines of greatest current density, the potential distribution appears to deviate very little from that for a polarized sphere.

[4] S. Yüngül, *Prof. Thesis*, California Institute of Technology (1945).

[5] J. J. Breusse, *Engineering and Mining Journal*, *133* (1932), 338.

[6] E. Poldini, *The Mining Magazine*, *60* (1939), 25.

Measurements along the line xy give the following results:
$V_{min} = -22$ units; $V_{max} = 12$; $V_{1/2} = -5$;
$a/(x_{min} - x_{1/2}) = 2.52$.
Curve (d) gives $\alpha = 25°$. From curve (c) for $\alpha = 25°$: $a/h = 1.75$; $h = 79$ feet.
Curve (b): $x_{min}/h = 0.15$ or $x_{min} = 12$ feet.

The thus determined center of the ore body and also the calculated dip are indicated in Figure 8. The agreement with the data obtained from the drill holes 1 and 2 is perfect.

Acknowledgments are made to Dr. G. Potapenko under whose direction the work has been carried out and to Mr. William E. Messner of the Surcease Mining Company for permission to publish the above data.